Planning for a Long-Term Optical Demonstration from the International Space Station

J. V. Sandusky and J. R. Lesh

Optical Communications Group
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109-8099

ABSTRACT

The Optical Communications Group at the Jet Propulsion Laboratory will deploy an optical communications transmitter demonstration and facility to the International Space Station in January 2002. The purpose of the demonstration is to establish a Gbps-class downlink from the International Space Station to ground and measure the flight terminal's performance. A large number of downlink passes are required to accurately measure the flight terminal's performance and the International Space Station provides such a long-term demonstration opportunity. The International Space Station simultaneously provides a payload-friendly environment. In this paper we discuss the objectives of the optical communications demonstration as well as the schedule for and issues related to the design, construction, and deployment of the flight terminal.

Keywords: optical communication, International Space Station, lasercomm

1. INTRODUCTION TO FREE-SPACE OPTICAL COMMUNICATION

Optical communication is commonly achieved in ground fiber-optic networks, where lasers are modulated and their output propagated through optical fibers to the receiver. In free-space optical communication, no transmission medium is used. Rather, laser beams are propagated through the atmosphere or the vacuum of space. As bandwidth in the radio-frequency domain has become increasingly scarce in recent years, future satellite networks including Teledesic have baselined optical communications technology to provide intersatellite links. Optical communications technology is able to provide high bandwidth intersatellite links without the regulatory constraints and cross-talk problematic in the radio-frequency domain.

In addition to the commercial development of free-space optical communication, the National Aeronautics and Space Administration (NASA) through the Jet Propulsion Laboratory (JPL) is developing optical communication for deep-space applications as a method to achieve NASA's goal of smaller, lighter, less expensive spacecraft possessing increased communications rates. Optical communication technology reduces mass, power consumption, and volume compared to radio-frequency technology[1]. As part of this technology development, the Jet Propulsion Laboratory has built a laboratory-model optical communications terminal called the Optical Communications Demonstrator (OCD)[2,3]. A photograph of the OCD mounted on an altitude / azimuth gimbal is shown in Figure 1. Its mass is less than 15 kg including the gimbal and its primary aperture is 10 cm in diameter.

Send all correspondence to John Sandusky
email: John.V.Sandusky@jpl.nasa.gov; telephone: 818-354-9388; fax: 818-393-6142

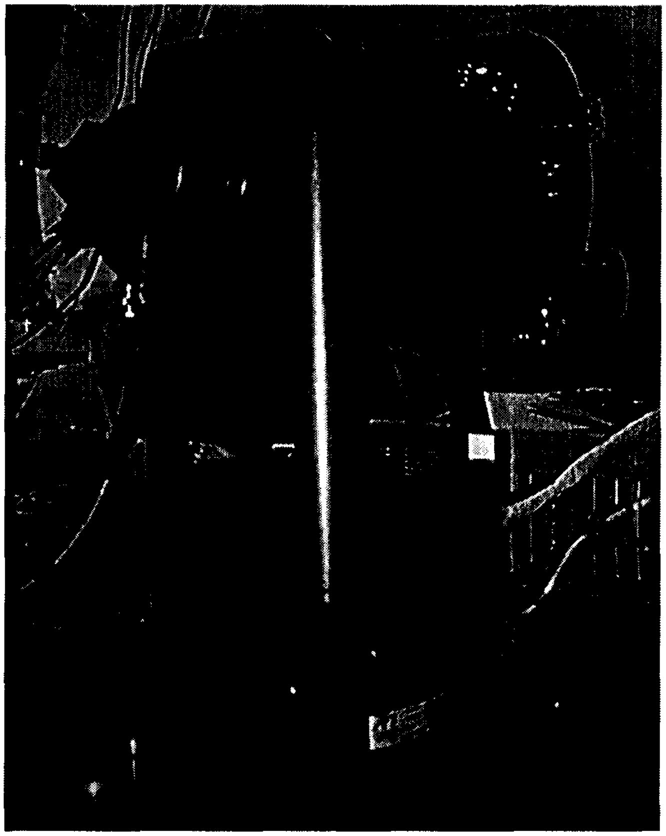

Figure 1: The Optical Communication Demonstrator (OCD), a laboratory-qualified optical communications terminal mounted on an altitude / azimuth gimbal. Its primary aperture is 10 cm in diameter and its mass is less than 15 kg including the gimbal.

The OCD architecture reduced size, complexity and power consumption compared to prior beam control systems which required as many as four detectors and four steering elements to perform pointing and tracking functions. The OCD architecture is based on a very simple implementation of the beam control system, utilizing only one detector array and one steering mirror. Figure 2 illustrates the concept for this system. The receiver station illuminates the flight terminal with a laser beam. This reference beam, termed a 'beacon', is imaged onto the flight terminal's detector array and provides directional reference. The downlink communications laser is also imaged onto the detector array, and the direction of the downlink beam is maintained relative to the beacon laser by adjusting the pointing of the downlink beam with a single fine-steering mirror.

The OCD has been demonstrated in the laboratory and is scheduled to perform a ground-to-ground demonstration in May 1998. This will investigate the OCD's ability to perform under the influence of a large amount of atmospheric turbulence, scintillation, and scattering loss. An air-to-ground demonstration is expected the following year. In this paper we discuss plans for a space-to-ground demonstration which will investigate the capability of an OCD-type optical communications terminal to operate in a space environment.

2. DEMONSTRATION OBJECTIVES

The objectives of the demonstration are to establish a Gbps-class downlink from the International Space Station to ground and measure the performance of the flight unit. The ground terminal for the demonstration will be the Optical Communication Telescope Laboratory[4] which is essentially an altitude / azimuth -mounted telescope having a primary mirror

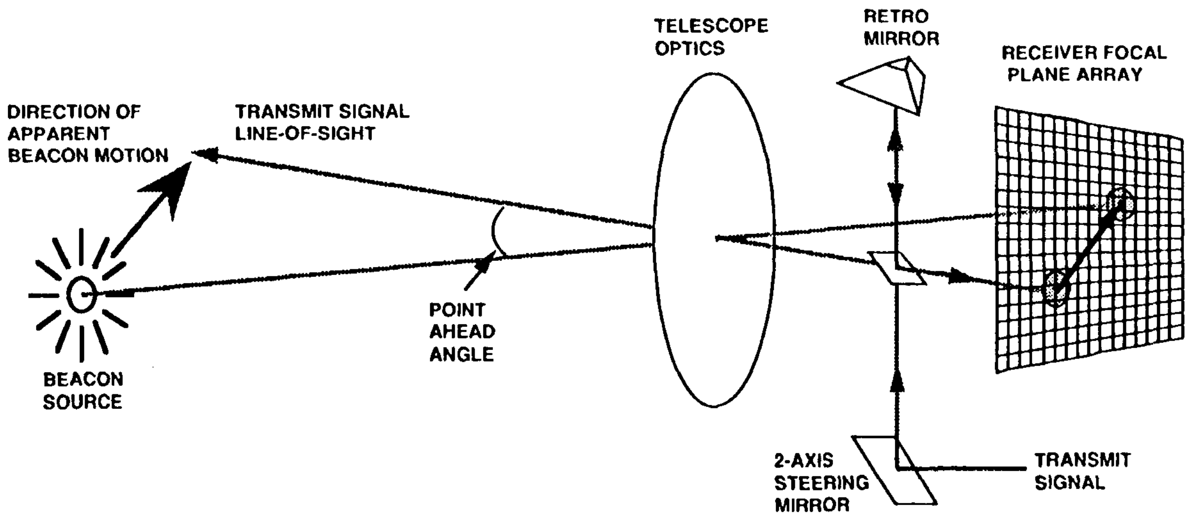

Figure 2. The architecture of the Optical Communication Demonstrator. Both the beacon beam from the ground station and the downlink laser beam are imaged onto the detector array, providing a measure of their relative directions. A steering mirror adjusts the pointing of the downlink beam to maintain the separation and orientation of the images at the pre-determined point-ahead angle.

nominally 1 meter in diameter. OCTL will be built at the Jet Propulsion Laboratory's Table Mountain Facility near Wrightwood, CA, and is expected to be completed in early 2000.

The performance of the flight unit can be characterized by several parameters. One parameter is the amount of time taken to acquire and lock onto the beacon beam provided by the ground station. Another parameter is the flight terminal's ability to maintain track of the beacon beam, measured in terms of the number of times which track is lost once established. The primary causes of loss of track are expected to be large-amplitude platform vibrations and scintillation on the uplink beacon. The flight unit will include an on-board accelerometer measuring platform vibrations transverse to the uplink beacon. Correlating this platform vibration information with the frequency of lost tracks will result in an improved understanding of the flight unit's performance.

Ultimately, the performance of the optical communications link is determined by the received bit error rate (BER) and number of fades. These performance parameters are influenced by several factors including the flight terminal's tracking subsystem performance, the vibration environment, and atmospheric effects such as atmospheric transmission loss (scattering and absorption) and scintillation, both on the uplink beacon and downlink beam. The atmospheric transmission is monitored by an autonomous visibility monitoring (AVM)[5] station so that atmospheric transmission can be correlated with the BER to facilitate further understanding of the systems performance.

It is necessary to observe a large number of downlink transmissions in order to make a statistically meaningful measurement of these flight terminal performance parameters. The planned orbit of the International Space Station will bring it more than 20 degrees above the ground station's horizon, creating a link opportunity, approximately twice per day. If one-third of the opportunities are clouded out, it will take approximately 75 days to observe 100 links. If we add to this duration a margin for unforeseen difficulties in observing the downlink as well as additional time to try new techniques, a flight duration of approximately 150 days is desirable. The International Space Station (ISS) provides such a long-duration flight opportunity. When the demonstration objectives have been fulfilled, the terminal will make its Gbps-class downlink capability available to other experimenters on the same EXPRESS Pallet. In this manner, the flight terminal functions not only as a demonstration, but also as a facility.

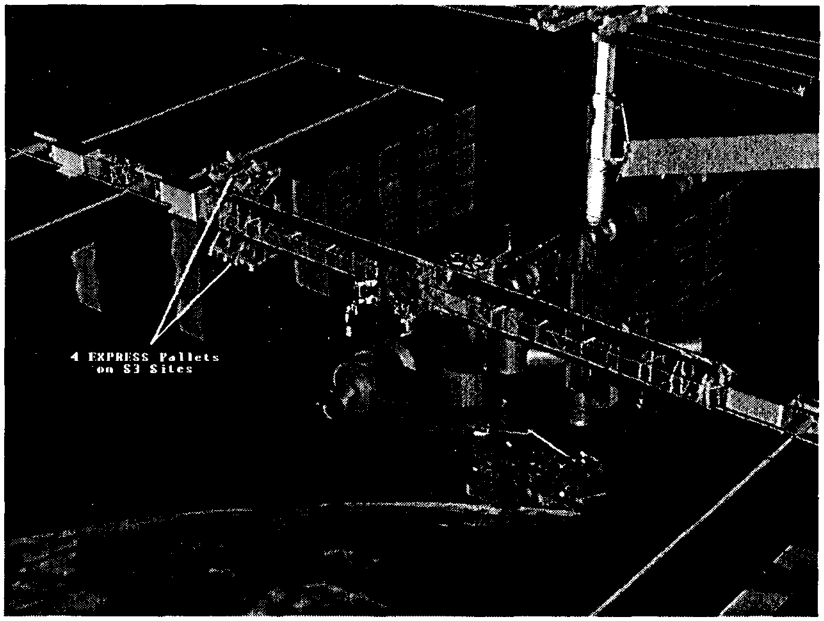

Figure 3. The International Space Station. Four sites are provided along the starboard truss for the attachment of EXPRESS Pallets.

3. THE INTERNATIONAL SPACE STATION

The International Space Station is shown in Figure 3. "The purpose of the ISS is to provide an orbiting vehicle to accommodate engineering research, microgravity research, and life and natural sciences research."[6] It will be the result of a cooperative effort of 16 nations: the United States, Canada, Belgium, Denmark, France, Germany, Italy, Netherlands, Norway, Spain, Sweden, Switzerland, United Kingdom, Russia, Japan, and Brazil. In partial fulfillment of its goal of

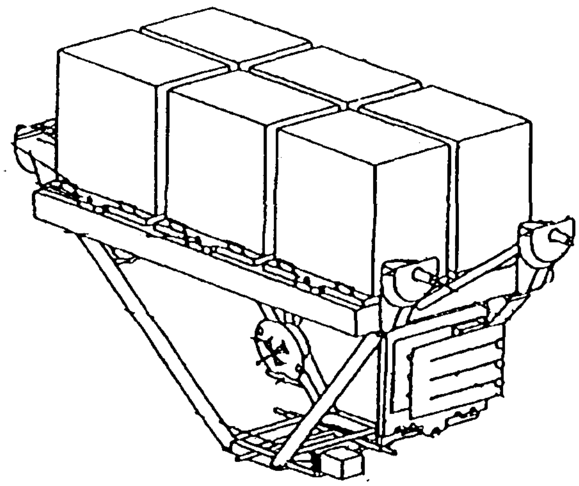

Figure 4. The EXPRESS Pallet. Each payload integrates to an EXPRESS Pallet Adapter. Six EXPRESS Pallet Adapters integrate onto one EXPRESS Pallet, and the EXPRESS Pallet integrates onto the International Space Station at one of the starboard truss sites.

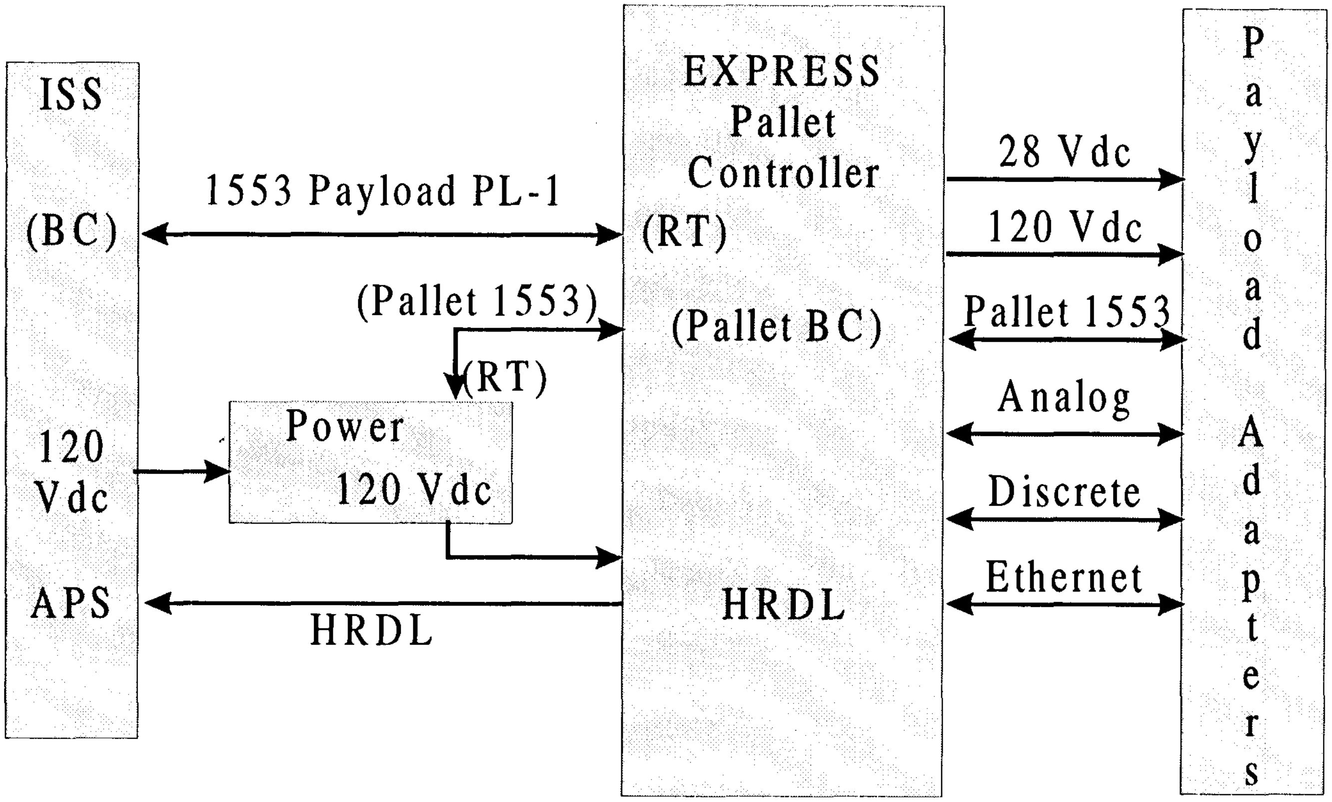

Figure 5. The EXPRESS Pallet System. The EXPRESS Pallet Controller interfaces the EXPRESS Pallet to the International Space Station electrical and data systems and regulates data and electrical services to the payloads.

accommodating engineering research, four external sites have been provided along the starboard truss, as indicated in Figure 3. The four sites, in aggregate, provide for 24 payloads and access to ram, wake, nadir, zenith, and earth limb. Each of the four sites accepts an Expedite the Processing of Experiments onto the International Space Station (EXPRESS) Pallet.

The EXPRESS Pallet System is the interface between user payloads and the ISS. The concept of the EXPRESS Pallet is illustrated in Figure 4. The user payload is integrated to the EXPRESS Pallet Adapter, which is essentially a bolt-hole grid with standard electrical and data connectors. Six EXPRESS Pallet Adapters are then attached to the EXPRESS Pallet, and the EXPRESS Pallet is attached to the ISS at the starboard payload attach sites. Each EXPRESS Pallet Adapter can be installed and removed individually without interrupting power to adjacent Adapters. Removal and installation will be accomplished with the Space Shuttle's extra-vehicular robotics (EVR) capability.

The heart of the EXPRESS Pallet system is the EXPRESS Pallet Controller (ExPC) which regulates the data and electrical interface between the ISS and the payloads. The concept of the ExPC is illustrated in Figure 5. Command and control functions will be handled over the MIL-STD 1553B data bus, with the ExPC acting as a remote terminal of the ISS and as a bus controller for the payloads. The ExPC also handles the High-Rate Data Link (HRDL) which provides a 43-Mbps link from payloads to ground for the purpose of relaying data. In addition to these data management tasks, the ExPC interfaces to the ISS electrical system and regulates electrical power distribution to the payloads. The six payload sites are provided with an aggregate of 3 kW of power at 120 Volts and 1.0 kW at 28 volts. In addition, digital and analog connections are available.

4. PLAN AND SCHEDULE

The schedule for the development of the flight terminal is shown in Figure 6. The initial phase of the development, the Conceptual Design Phase, was completed in November 1997. In the Conceptual Design Phase, we clarified the purpose and goals of the demonstration and facility, and outlined the operations of the terminal. The project is presently in the Systems Definition Phase, specifying the purpose and capability of each subsystem and its interfaces. The Systems Definition Phase, expected to be completed in March 1998, will be followed by the Preliminary Design Phase. During the Preliminary Design Phase we will design and specify the hardware and software for each subsystem, culminating in a Preliminary Design Review in August 1998. Following the Preliminary Design Review, we will enter the Critical Design Phase in which final design changes will be introduced to the system. After the Critical Design Review, hardware fabrication and subsystem integration will begin in earnest. The complete flight terminal should be assembled and ready for thermal, vacuum, and vibration tests by June 2000, culminating in the delivery of the flight hardware in February 2001. Launch of the first EXPRESS Pallet, integrated with payloads, is scheduled for flight UF-4 in January 2002.

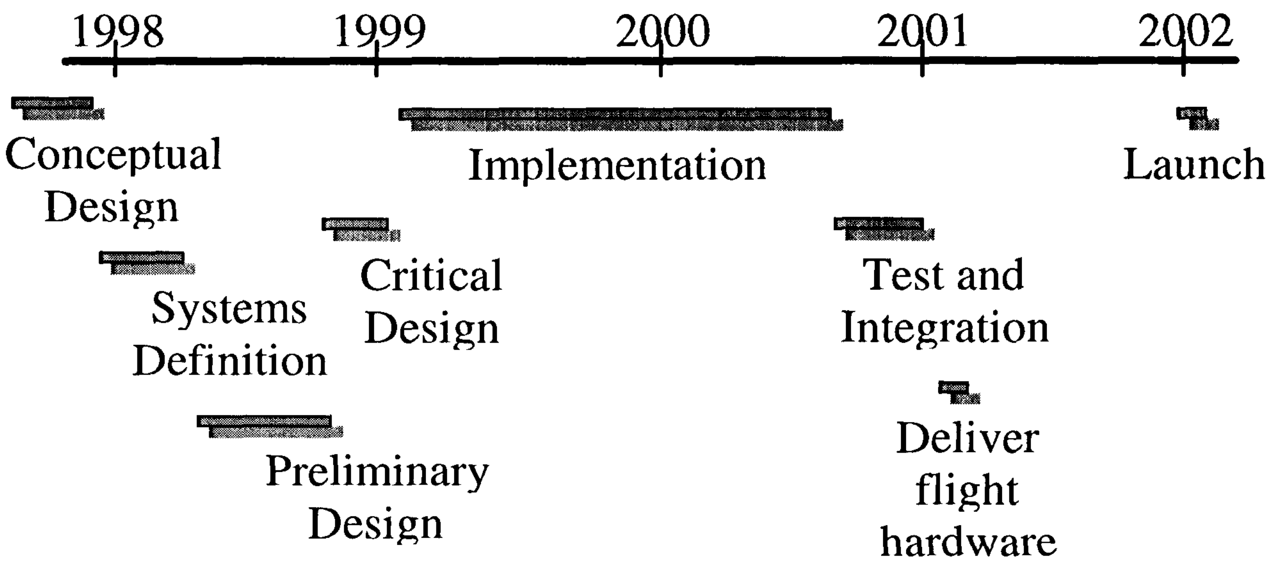

Figure 7. Schedule for the design and development of the flight terminal.

9. SUMMARY

In summary, the Jet Propulsion Laboratory will deploy a Gbps-class optical communications transmitter demonstration and facility to the International Space Station in January 2002. The initial phase of the program has already been completed, and the first design review is scheduled for August 1998. The demonstration will measure the performance of the flight terminal in terms of bit error rate, fade probability, and the frequency of tracking errors. These measures will be correlated with both atmospheric transmission measurements made by an autonomous visibility monitoring station and accelerometer data from the flight terminal. These correlations will facilitate an in-depth understanding of the flight terminal's performance. The International Space Station provides an excellent platform from which to make the large number of observations necessary to achieve a good statistical measure of the flight unit's performance.

ACKNOWLEDGMENT:

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